Short Communication

CAN AXES CONVENTIONS OF THE TRUNK REFERENCE FRAME INFLUENCE BREAST DISPLACEMENT CALCULATION DURING RUNNING?

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Abstract

To obtain breast motion relative to the trunk, skin markers are used to define a local coordinate system (trunk), with respect to the global reference frame. This study aimed to quantify any differences in multiplanar breast displacement relative to the trunk using the first axis of rotation as either the mediolateral or longitudinal axis. Ten female participants ran on a treadmill (10 kph) in three different breast supports (no bra, everyday bra, sports bra). Four reflective markers placed on the trunk and right nipple were tracked using eight infrared cameras (200 Hz) during five running gait cycles in each breast support condition. Following marker identification, right breast multiplanar displacements were calculated relative to the trunk using either the mediolateral axis or the longitudinal axis as the first rotational axis to define the orthogonal local coordinate system. Results showed that there was a significant difference (8.2%) in superioinferior breast displacement in the sports bra condition when calculated using different axes conventions for the trunk segment. Furthermore, the greatest magnitude of breast displacement occurred in a different direction depending upon the selection of the first rotational axis. The definition of the primary reference axis of the trunk significantly alters the magnitude of superioinferior breast displacement and therefore it is recommend that the previously reported 'stable' longitudinal axis should be defined as the first rotational axis during running. Caution should also be used as the axes convention influences the magnitude and direction of breast support requirements, which has important implications for bra design.

Keywords: kinematics; axes; thorax; model

Introduction

The analysis of human movement in three dimensions requires the determination of the instantaneous position and orientation of the points of interest. To obtain breast motion relative to the trunk, skin markers have been used to define a local coordinate system (trunk), with respect to the global reference frame (Scurr et al., 2010; Zhou et al., 2012). The order in which the axes of the local coordinate system are constructed may affect the calculated relative breast motion since these define the directional components of breast displacement.

Two main practises have been utilised for the calculation of multiplanar breast kinematics. Scurr et al., (2010; 2011) define the mediolateral axis as the first axis of rotation using the normalised vector from a marker on the right anterior aspect if the 10th rib to the same point on the left. A marker on the suprasternal notch was then used to construct the trunk reference plane where the remaining vectors were defined using the right hand rule. In contrast, the International Society of Biomechanics (ISB) recommendations (Wu et al., 2005) define the longitudinal axis of the trunk first, from the midpoint of markers placed on the eighth thoracic vertebrae and the xiphoid process and the mid-point of the suprasternal notch and the seventh cervical vertebrae pointing upward, the other axes are then defined using the right hand rule (Wu et al., 2005). The ISB marker locations can be problematic within breast biomechanics due to the breasts or bra straps covering some of the markers. Although different markers locations were used in these examples the key factor for consideration within this paper is the selection of the first rotational axis, which has yet to be considered in breast biomechanics literature.

The majority of breast biomechanics research utilises running as the main exercise modality (Scurr et al., 2009; 2010; 2011; White et al., 2009; McGhee et al., 2007), and previous research on running has identified that the greatest trunk rotation occurs about the longitudinal axis (Saunders et al., 2005). It is recommended that during running the longitudinal axis is defined first as this is most likely to remain ‘stable’ (Kontaxis et al., 2009), however if the mediolateral is defined first, instability of any rib markers (Scurr et al., 2011), due to breathing (Chopra et al., 2006) and soft tissue motion (Heneghan and Balanos, 2010) may compromise both the mediolateral and longitudinal axes, thus effecting breast displacement in these directions.

Multiplanar breast displacement is common in breast biomechanics research and is often used as a measure of the support provided by a bra. This measure has been used to provide bra manufacturers with recommendations for bra design to reduce multiplanar breast displacements and improved breast support and comfort (Zhou et al., 2012). However, the magnitude of segment kinematics have been shown to differ depending upon the order in which the axes are defined for the segments (Kontaxis et al., 2009), therefore it is possible that the magnitude of breast kinematics may differ depending upon the selection of the first axis of rotation in the trunk reference frame. With this in mind the quantification of any differences in breast displacement may act as a valuable resource for researchers when defining the first axis of rotation for the local coordinate system for the trunk during running. This study aims to quantify the influence of defining the mediolateral or longitudinal axis as the first axis of rotation on breast displacement during running.

It is hypothesised that there will be significant differences in breast displacement during running relative to the trunk when defining the first reference axis of rotation as either the mediolateral or longitudinal axis.

Methods

Following institutional ethical approval and written informed consent, ten females (age 22 ± 2 years, height 1.65 ± .04 m, body mass 61.0 ± 2.4 kg) were selected to participate in this study if they were recreationally active, aged between 18 and 40 years, were not pregnant, had no history of breast surgery, had not given birth or breast-fed in the last year, and were a UK 32D breast size (assessed using the bra fitting criteria set out by White and Scurr, 2012).

Participants completed a self directed treadmill warm up (H/P/Cosmos Mercury, Germany). Following the warm up, retroreflective passive markers (.006 m radius) were positioned on the suprasternal notch, left and right anterior inferior aspect of the 10th ribs, and on the right nipple (Scurr et al., 2011). A nipple marker has previously been shown to be a reliable and valid measure of gross breast displacement (Mason et al., 1999). An additional heel marker was added to track gait cycles (Scurr et al., 2010). Three dimensional movement of the markers were tracked using optoelectronic cameras sampling at 200 Hz (Oqus, Qualisys, Sweden), positioned in an arc around the treadmill. Cameras were calibrated using a coordinate frame positioned on the treadmill and a handheld wand containing markers of predefined distances (QTM [Qualisys Track Manager]; version 1.10.828, Qualisys, Sweden).

Participants ran at 2.8 $m.s^{-1}$ for a two minute familiarisation period, after which marker coordinates were recorded for five gait cycles (Scurr et al., 2010; 2011) in three breast support conditions (no bra, everyday bra and sports bra). The everyday bra was a Marks and Spencer Seamfree Plain Under wired T-Shirt Bra, non-padded, made from 88% polyamide and 22% elastane lycra and the sports bra was the UK's best-selling branded encapsulation sports bra (Shock Absorber Run bra, made from 81% polyamide, 10% polyester, 9% elastane).

Markers were identified and reconstructed in QTM, raw data were filtered using a second order low pass Butterworth filter with a cut off of 13 Hz and exported into a transformation matrix (Foley et al., 1995). In the first case (Reference frame 1) the normalised vector between the right and left rib markers created the first axis of rotation (Y_1). The suprasternal notch marker was then used to construct two vectors within the trunk reference plane (vector 1 extending from the suprasternal notch to the left rib, and vector 2 extending from the right rib to the suprasternal notch). The normalised cross product between vectors 1 and 2 defines the second axis (X_1). The final orthonormal axis (Z_1) was created using the cross product between X_1 and Y_1. This defined a right handed local co-ordinate system for the trunk with X_1 representing the anterioposterior direction, Y_1 representing the mediolateral direction and Z_1 as the superioinferior direction (Figure 1a). In the second case (Reference frame 2) the right and left ribs were used to calculate a virtual mid-rib point. The normalised vector extending from the mid-rib point to the suprasternal notch defined the longitudinal axis as the first reference axis (Z_2). The suprasternal notch marker was then used to construct two vectors within the trunk reference plane (vector 1 extending from the suprasternal notch to the left rib, and vector 2 extending from the right rib to the suprasternal notch). The normalised cross product between vectors 1 and 2 defines the second axis (X_2). The final orthonormal axis (Y_2) was defined using the cross product between Z_2 and X_2. This defined a right handed local co-ordinate system for the trunk with X_2 representing the anterioposterior direction, Y_2 representing the mediolateral direction and Z_2 as the superioinferior direction (Figure 1b). In both cases the suprasternal notch was defined as the origin when calculating right nipple coordinates relative to the trunk (Scurr et al., 2010).

**** Insert figure 1 here ****

Breast displacement (relative to the trunk) was calculated using both reference frames by subtracting the minima positional coordinates from the maxima during each gait cycle (Scurr et al., 2010). The five gait cycles were identified using the anterioposterior velocity of the heel marker (Zeni et al., 2008). Mean breast displacement was calculated using the five gait cycles for each support condition using each reference frame.

All data were checked for normality using the Kolmogorov-Smirnov and Shapiro-Wilks tests, then either a paired samples T-test or Wilcoxon Signed rank test were used to assess any differences in right multiplanar breast displacement between reference frame definitions (within each breast support condition).

Results

The magnitude of breast displacement in the anterioposterior direction did not significantly differ between reference frame definitions. The greatest difference in breast displacement, between the two reference frames, occurred in superioinferior direction (2.7 cm) in the everyday bra support condition (Figure 2), although this was also non-significant. The only significant difference occurred in the superioinferior direction, within the sports bra condition ($t = 2.597$, $p = 0.029$) between the two reference frame definitions.

**** Insert figure 2 here ****

The percentage distribution of multiplanar breast displacement did not change within the no bra condition between the two reference frames. However, in the everyday bra condition (reference frame 1), breast displacement was greatest in the superioinferior direction (42 %), followed by mediolateral (32 %) and anterioposterior (26 %), yet when implementing reference frame 2 the order changed to superioinferior (35 %), anterioposterior (33 %) then mediolateral (32 %) (Figure 2). Furthermore in the sports bra condition (reference frame 1) the greatest breast displacement occurred in the superioinferior direction (38 %), yet this direction represented the least breast displacement (29 %) when implementing reference frame 2 (Figure 2).

Finally, it was interesting to note that breast displacement calculated using reference frame 1 in the superioinferior and mediolateral directions were greater in the everyday bra than those found in the no bra condition (0.3 cm), suggesting that the breast displaces more when wearing an everyday bra than wearing no bra. This result was not replicated when using reference frame 2 (Figure 2).

Discussion

Within breast biomechanics research the first rotational (reference) axis of the trunk has been defined as either the mediolateral (Scurr et al., 2010) or longitudinal axis (Zhou et al., 2012). This study aimed to quantify any differences in breast displacement relative to the trunk that occur due to changing the first reference axis of the trunk when constructing the local co-ordinate system. Key findings showed that the definition of the primary reference axis of the trunk significantly alters the magnitude of superioinferior breast displacement in the sports bra condition, accepting the first hypothesis. Furthermore, the direction in which the greatest magnitude of breast displacement occurs also changes depending upon the selection of the first rotational axis used to create the local orthogonal axes of the trunk segment.

Results showed that the magnitude of anterioposterior breast displacement were the same in both reference frames due to the identical construction of the anterioposterior vector. The first rotational reference axis were defined as either the mediolateral or longitudinal axis therefore constraining the third vector to be orthogonal to the reference axis and anterioposterior axis.

Breast displacements in three dimensions are often reported (Bridgman et al., 2010; Scurr et al., 2011) and used to identify where aspects of bra design could be developed. Bridgman et al. (2010) discussed the importance of comparing the different directions of breast motion to help inform bra design and Scurr et al. (2011) also state that sports bras should predominantly reduce superioinferior displacement. The findings of this study would influence the recommendations made by previous researchers as the direction in which the greatest breast displacement occurs also depends upon the selection of the first rotational axis. For example, in the sports bra condition, the majority of breast displacement occurs in the superioinferior direction (reference frame 1), implying that this aspect of breast support needs to be improved, however, using reference frame 2, results suggest the least displacement occurs in this direction, therefore altering the aspect of breast support that needs improvement.

In conclusion, this study has demonstrated that the definition of the primary reference axis of the trunk significantly alters the magnitude of superioinferior breast displacement. Therefore, it is recommend that the previously reported ‘stable’ longitudinal axis should be defined as the first rotational axis during running and that caution used when making recommendations regarding bra design since the direction in which the greatest magnitude of breast displacement occurs, can depend upon the selection of the first rotational axis for the local reference frame.

Conflict of interest statement

The authors have declared no conflicts of interest associated with this research.

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Figure Captions:

Figure 1. Construction of trunk reference frame 1 (a) and reference frame 2 (b)

Figure 2. Mean (SD) relative multiplanar breast displacement during running calculated using the two trunk references frames across three breast support conditions (n = 10). * $p<0.05$.

Figure 1
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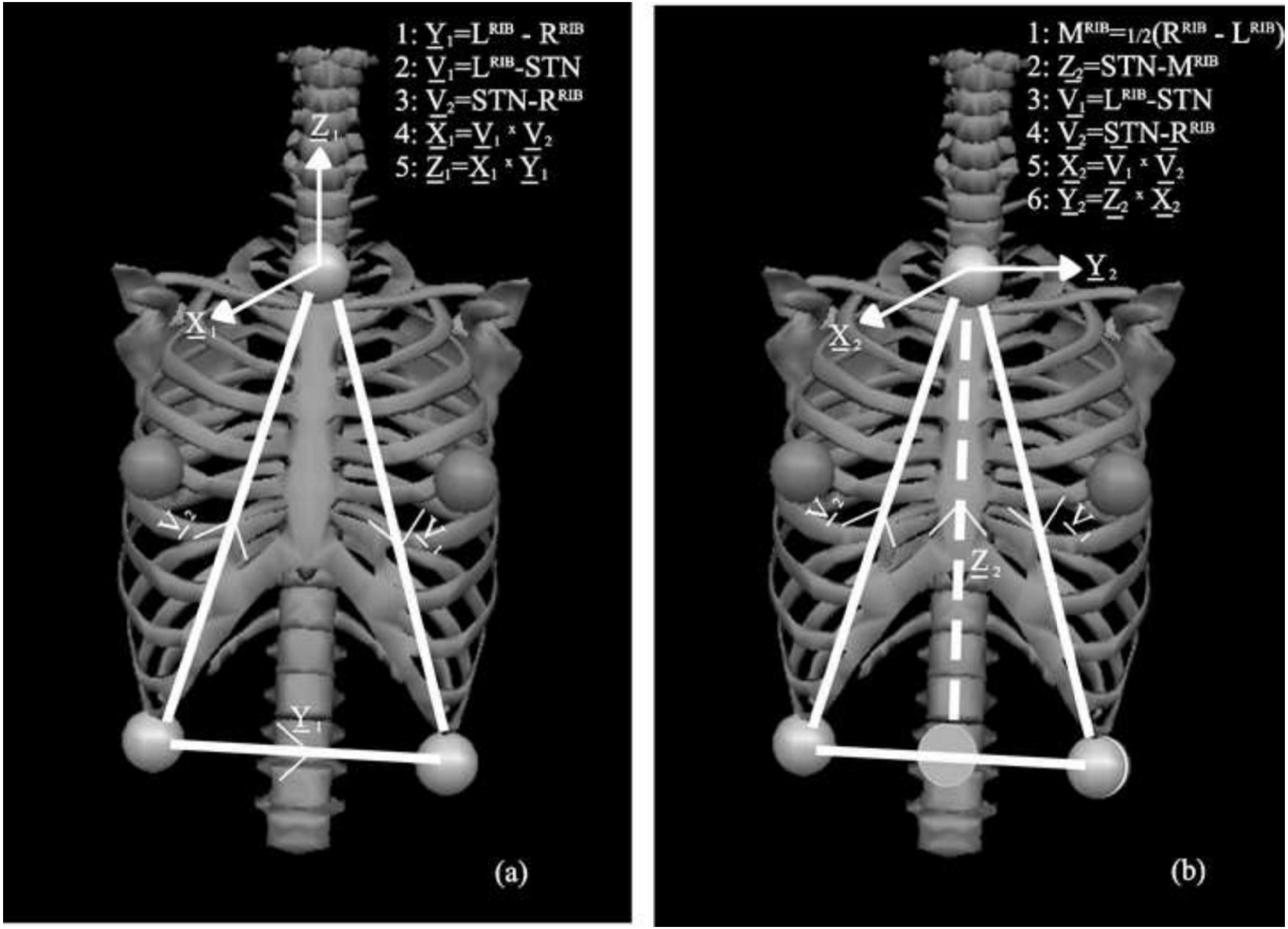

Figure 2
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